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White Sands Missile Range Urban Study: Flow and Stability Around a Single Building Part 1: Background and Overview

by Gail Vaucher

ARL-TR-3851 **July 2006**

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Computational and Information Sciences Directorate

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14. ABSTRACT

The U.S. Army Research Laboratory (ARL) serves the Army Soldier by providing research tools and resources. The atmospheric boundary layer (ABL), an area which begins at the surface and extends vertically to 1-2 km above ground level, is one of the ARL research areas. The lowest 10% of the ABL (a.k.a., surface layer) is the primary work environment for an Army Soldier. Characterizing this atmospheric surface layer was the focus of five field studies conducted between fiscal years 2001–2005 at White Sands Missile Range, NM. This report summarizes the surface layer research beginning with the rural environment studies and progressing into the subsequent urban setting. Appendices provide outlines and templates for conducting field research based on these successful field research studies. While this report provides an overview of these scientific investigations, it also serves as foundational material for reports documenting the Surface Layer and Urban Study research results in greater detail.

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Urban, surface layer, winds, stability, Urban Study.

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Preface

This technical report is the first of several reports documenting the White Sands Missile Range (WSMR) Urban Studies conducted by the U.S. Army Research Laboratory Battlefield Environment Division at WSMR, NM. The Urban Studies had two main areas of research: dynamic and thermodynamic atmospheric characterization around a single urban building. While this foundational report presents an overview and an historical scientific review of the urban research project, subsequent reports will provide greater detail of the investigation results.

Acknowledgments

All successful field studies are the result of people working together as a team. The White Sands Missile Range 2003 and 2005 Urban Field Studies were team efforts, indeed! Each participant listed below was a *critical* member of this research effort and, as Test Director, it was a pleasure to serve with them toward the common scientific goal of improving the U.S. Army Research Laboratory's understanding of the urban environment and the potential hurdles of urban warfare.

Here is a list of the participants and their primary responsibilities:

- Gail Vaucher: 2003/2005 Field Director/Lead Scientist (Objective #2)
- Ronald Cionco: 2003/2005 Lead Scientist (Objective #1)
- Manuel Bustillos: 2003/2005 Campbell Systems Lead
- Sean D'Arcy: 2005 Ultrasonic Systems Lead
- Robert Dumais: 2005 Mesoscale/Synoptic Meteorology Lead
- SFC Robert Brice: 2003/2005 Military Liaison

Not mentioned in the list are the administrative staff (whose support helped keep the communication lines flowing) and the Soldiers (who volunteered their time to assist with the tower construction and removal). We greatly appreciate their willing attitudes and inquiring questions. And, hope that the fruit of this study will someday make the Soldier's job a little safer and easier. I look forward to the continued team effort toward building better tools for the Soldiers.

Executive Summary

The main focus of the U.S. Army Research Laboratory (ARL) is serving the Army Soldier. This is accomplished by providing research tools and resources. One of the Battlefield Environment Division's research areas is the atmospheric boundary layer (ABL). Physically, the ABL begins at the surface and can extend vertically to 1-2 km above ground level. The lowest 10% of the ABL is called the "surface layer." Within this layer is where much of the Army's activities reside. Characterizing this surface layer was the focus of five field studies that occurred between fiscal years 2001–2005 at White Sands Missile Range, NM. This report summarizes the evolution of the surface layer research beginning with the rural environment and progressing into the urban setting.

In the early 2000s, the U.S. Army vision was "to see first, act first …." Optimal seeing conditions naturally occur when a nighttime stable atmosphere transitions into an unstable daytime atmosphere, and visa versa. These diurnal transitions are called "Stability Transitions" (ST), or "Neutral Events," and are observed within the surface layer. The first step in the surface layer ST research was to design rural surface layer ST field studies based on an operational model called the *ST Forecast Model*. The field study objectives were to validate/verify the *ST Forecast Model* capability at a non-operational, remote desert site and to empirically investigate additional characterizing patterns within the surface layer. In 2001, the rural ST studies were conducted during the equinoxes and a solstice. The results validated the *ST Forecast Model*, provided examples of Multiple- and Extended-Neutral Events case studies, and served as a foundation for the subsequent urban ST investigations.

Interest in the successful rural study evolved into ST research in a small complex of office buildings. This new ST study asked whether the *ST Forecast Model* would be applicable in the urban environment. Complimenting this objective, the validity of the Snyder/Lawson 1994/1995 Wind Tunnel Study Results was also examined. Two subsequent field studies addressed both issues. An overview of the *WSMR 2003* and *2005 Urban Studies* construction and the preliminary dynamic and thermodynamic results are included in this report. In short, the WSMR Urban Studies' preliminary dynamic results found that a single building does indeed disturb the airflow and the turbulence behavior. The wind tunnel pattern generated by the single building obstruction was validated with tower data collected in both the *WSMR 2003 Urban Study* and *WSMR 2005 Urban Study*. These features included a fetch flow, an accelerated flow over the roof, a velocity deficit and flow reversal (cavity flow) on the building leeside, leeside corner vortices, and a leeside reattachment zone.

The WSMR Urban Studies' preliminary thermodynamic results found that a single building can create its own urban heat island. The thermodynamic patterns around the single building reported both a rural and urban cycle of stability. While these measurements do not represent a large city, patterns of a larger building complex were observed that included stable, unstable, and neutral vertical profiles. The stable conditions in the *WSMR 2005 Urban Study* characterized about 6% of the time sampled. The preferred time of occurrence for stable conditions was

around midnight. The Eastern tower reported the greatest number of minutes in a stable environment, followed by the Northern tower, which had the second largest number of stable minutes.

The results of this research impact the Soldier in several ways. Regarding the building corner vortices, one of the impacts for the Soldier is that these vortices can lead to elevated concentrations of airborne elements on the leeside of the building. Combining these corner vortices with a leeside cavity flow could easily bring toxins released on the windward side of a building into a centrally located front door/emergency exit. Knowledge of such flow patterns could be crucial intelligence in strategizing safe/healthy retreats from office buildings.

Another impact of this research would be on the Soldiers' ability to use thermal sighting when working in a quasi-thermally well-mixed environment. When rural nighttime conditions (stable/neutral) prevail, the effectiveness of thermal sighting should improve significantly. Another military application is in the area of simulation and modeling that includes weather features. Most chemical-biological-nuclear simulations presume "neutral" atmospheric stability. Data from these studies indicated that all three stabilities (neutral, unstable, and to a lesser extent, stable) do occur and their effects should be used as potential information for the military strategist. For Soldiers using laser technology, knowing model results from the unstable (urban heat island) environments could have a major impact on their mission effectiveness.

1. Army Interest in the Atmosphere

The main focus of the U.S. Army Research Laboratory (ARL) is serving the Army Soldier. The 2006 Computational and Information Sciences Directorate (CISD) mission includes weather decision aids research (ARL, 2006). Before one can develop useful weather decision aids, an understanding of the atmospheric character and how this impacts Army decision making is required. One area of the atmosphere that greatly impacts the Soldier is the atmospheric boundary layer (ABL). Physically, the ABL begins at the surface and can extend vertically to 1-2 km above ground level (AGL). The lowest 10% of the ABL is called the "surface layer." Within this layer is where much of the Army's activities reside. Characterizing this surface layer was the focus of several ARL-Battlefield Environment Division Surface Layer Field Studies that occurred between fiscal years 2001–2005 at White Sands Missile Range (WSMR), NM. An overview of this research will be discussed within this report, beginning with the rural atmospheric surface layer studies and progressing into the subsequent urban environment.

1.1 Rural Surface Layer Stability Transition Research

In the early 2000s, U.S. Army Chief of Staff Shinseki stated that his U.S. Army vision was "to see first, act first …." In keeping with this vision, ARL focused their surface layer research on naturally occurring atmospheric patterns that enhance and detract from the Army and Navy "seeing" missions. Optimal seeing conditions naturally occur when a nighttime stable atmosphere transitions into an unstable daytime atmosphere, or an unstable daytime atmosphere transitions into a stable nighttime atmosphere. These diurnal transitions are called "Stability Transitions" (ST), or "Neutral Events," and are observed within the lowest 10% of the ABL. Benefits of knowing when the ST will occur include 1) providing knowledge of when chemical and biological weapon effects would shift from foe (toxic concentrations in a limited area) to friendly (non-toxic concentrations in a broad area) and visa versa; 2) improving the initialization of the convective boundary layer growth phase, which in turn impacts civilian and military atmospheric dispersion/diffusion model accuracy; and 3) knowing when a smoke screen would "clear" (due to convective mixing), which would provide a strategic advantage for battle strategy planners.

The first step in the ST research was to design three rural surface layer ST field studies based on a 1994/1995 *Stability Transition Forecast Model* for the southwestern U.S. desert region, published by Vaucher and Endlich (1994, 1995). This model was developed and used operationally at an Army-owned laser test facility. The objectives for the three field studies were to validate/verify the ST forecasting capability at a non-operational, remote desert site and to empirically investigate additional characterizing patterns within the surface layer. In 2001, the three field studies were conducted over the March and September equinoxes and the June solstice time periods. The results validated the *ST Forecast Model* in an alternate rural, remote, desert site location; provided examples of Multiple- and Extended-Neutral Events case studies; and served as a foundation for the subsequent urban stability transition study. More detailed information on these studies can be found in the following ARL technical reports: ARL-TR-2798, March 2001 (Vaucher and Bustillos, 2003); ARL-TR-2823, June 2001 (Vaucher and Bustillos, 2003); and ARL-TR-2827, September 2001 (Vaucher and Bustillos, 2003).

1.2 Urban Surface Layer Stability Transition Research

A new surface layer field study focus arose from the question of whether the recently validated rural *ST Forecast Model* could be utilized in an urban environment. Before answering that question, however, a background check of what was already known about Army interests in the urban environment was pursued. Section 2 summarizes the findings.

2. Urban Warfare

The atmospheric contributions to urban warfare can be subdivided into at least two perspectives: military (Army) and scientific (research). For the military, there are ground and air arenas, as well as Army missions and functions, to be considered.

Subset topics to the Army missions/functions include, but are not limited to, Strategy/Planning, Reconnaissance/Surveillance, Communications, Mobility, Weapons, and Logistics.

The scientific interests include even more detailing aspects, such as:

- Modeling (such as boundary layer, canopy, airshed, etc.)
- Field Experiments (Vertical Transport and Mixing (VTMX), Basel Urban Boundary Layer Experiment (Bubble), etc.)
- Urban Heat Island (and Humidity Island)
- Urban Cool Island (vegetation-atmosphere interactions)
- Urban Biometeorology
- Urban Radiation/Energy Exchange
- Urban Micrometeorology
- Flow and Dispersion
- Surface Databases
- Air Pollution
- Atmospheric Chemistry

When studying Army urban warfare, the primary strategy/rule given was to avoid engaging the enemy at all while in an urban environment. When this rule becomes impossible, experience yielded several “lessons learned.” Using a Web site reference from the Center for Army Lessons Learned (CALL) (1999), the dominant atmospheric parameters cited include effects of winds, wind patterns, cloud ceilings, visibility, temperatures, and illumination problems. More specifically, some of the dynamic impacts documented were in the area of urban flight operations. Broken-up and street/alley funneling winds and canyon turbulence adversely affected aircraft performance and weapon delivery. The “Aviation Urban Operations” manual (2001) associated wind patterns with the degradation of night vision systems, communications, visibility, and toxic fumes.

Some of the urban environment thermodynamic impacts reported included adverse affects on military aircraft thermal sights, reduced visibility due to urban smog, and a severe degradation of laser guided weapons. The thermal heating by buildings was cited as a potential explanation for the thermal sights effects. The reduced visibility due to urban smog was said to cause increased target acquisition threat exposure time and urban weapon sensor degradation. While this report will not address solutions to these issues, it will provide the atmospheric characterizations of the urban surface layer that are intended to lead to solutions.

2.1 Defining Urban

"Urban" can be defined as many things, from downtown city high-rise buildings clustered together to a loose ensemble of single-story residential buildings. The Army maintains its own definitions based on populations. Even the ABL structure exhibits a new sub-structure (figure 1, (Stull, 2000)) and presents numerous multi-variable cause and effect patterns, when associated with urban environments. Before attempting research in the urban meteorology discipline, a simplification of the problem needed to be addressed.

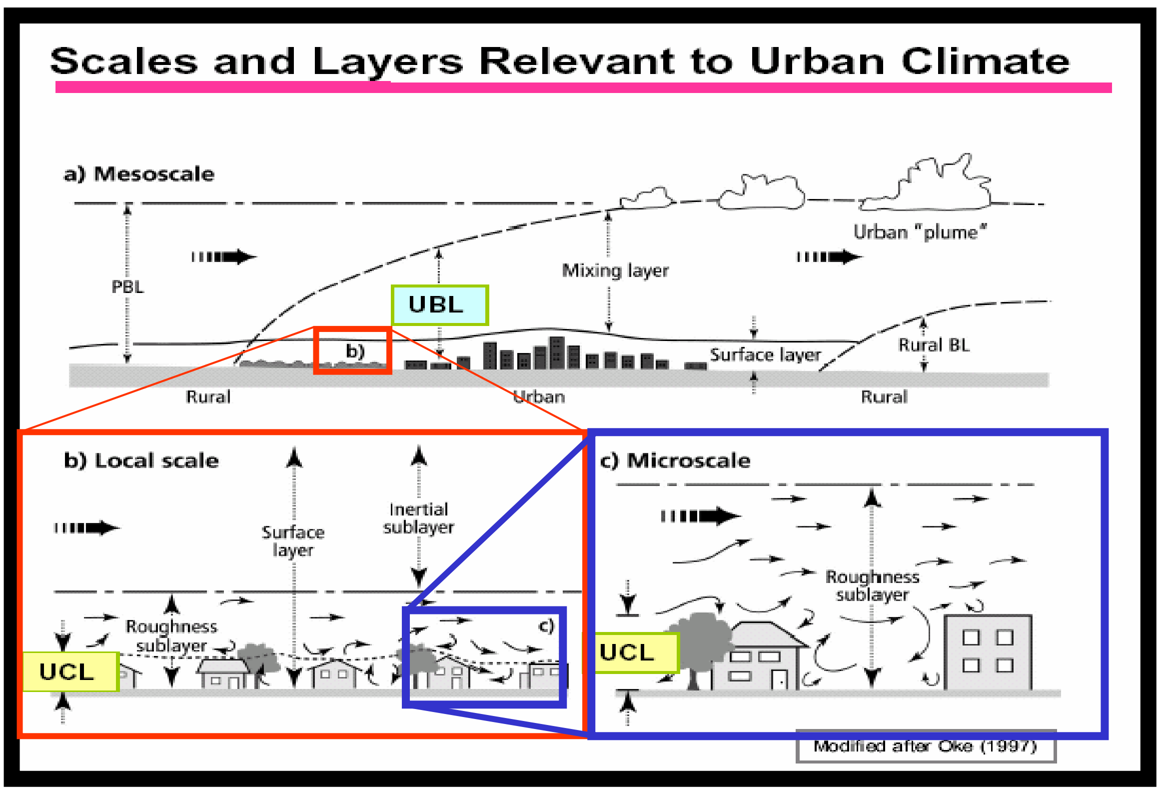

Figure 1. The ABL is also known as the Planetary Boundary Layer (PBL). The PBL over an urban area has two sub-structures, the local scale and microscale, according to Stull (2000).

2.2 Simplifying the Urban Meteorological Investigation

First, the logistical complexity in studying a downtown city high rise environment (Alwine et al., 2004) demanded that the initial field study be simplified by selecting a single building with a parking lot on one side and a loose cluster of buildings on the remaining sides. The population factor was left as a default function of the cluster of buildings. The atmospheric variables targeted for study were subdivided into dynamic and thermodynamic parameters. To optimize

dynamic pattern recognition, the March-April New Mexico “windy season” was selected for the field study. To minimize a seasonal influence on the thermodynamic character, the equinox time period was chosen for the equal heating/cooling cycles over a 24-h period. The field study objectives were divided into two distinct field exercises:

- The first field study focused on the mean dynamic and thermodynamic transition patterns.
- The second expanded the objectives to include the details (such as turbulence) in the dynamic and thermodynamic patterns.

Each field exercise is described and summarized in section 3.

3.   Urban Field Study

Two WSMR Urban Studies were constructed from the same foundational research. Each Study, however, had a unique focus. In the next sections, we describe the foundational research, the foci, and the subsequent sensor layouts.

3.1   Urban Study Objectives

In 2003, ARL addressed the dynamic and thermodynamic atmospheric impacts on urban warfare with the *WSMR 2003 Urban Study*. This field study’s scientific objectives included quantitatively investigating the following:

- The air flow behavior (mean) around and above a single building
- The characteristics of the urban environment surface layer ST patterns

Additional objectives for this 2003 WSMR field study were to pre-test the field study design and acquisition systems for the Joint URBAN2003 Oklahoma City Project, an urban downtown city field study. While not the focus of this technical report, it should be noted that the success of the *WSMR 2003 Urban Study*, also known as *PreTest #1*, did indeed provide justification and a significantly higher confidence level for ARL’s participation in the Joint URBAN2003 Oklahoma City diffusion/dispersion study.

In 2005, the successful initial study expanded the objectives to include the acquisition and study of more dynamic and thermodynamic details. The written mission objectives were as follows (Vaucher, 2004):

- To characterize behavior of turbulent flow around and above a single building
- To characterize surface layer stability patterns in an urban environment

3.2   Urban Study Design: Field Study Layout and Sensor Selection

The *WSMR 2003* and *2005 Urban Studies* design was based on a blend of two previous research studies:

- The thermodynamic portion was based on the 1994/1995 Vaucher and Endlich optical turbulence study (Vaucher and Endlich, 1994).

- The dynamic portion was based on a 1994 Snyder and Lawson wind tunnel study (Snyder and Lawson, 1994).

The field site selected for the WSMR Urban Study was within 5 miles of the previous three rural Surface Layer ST field studies described in section 1.1. The duration of both Urban Studies was about 2 weeks (March 25–31, 2003; March 21 to April 1, 2005). A pre-study dry run of the field equipment in 2003 also yielded interesting scientific results, and will be included in section 4.

3.2.1 2003 Urban Study Design

In the 2003 study, four gross features from the 1994 Wind Tunnel Study (Snyder and Lawson, 1994) were targeted for validation/verification. These included flow fetch, accelerated flow above the building, leeside velocity deficit, and leeside flow reversal (see figure 2). Tower positions with respect to the building structure were subsequently selected to optimize the ability to quantify aspects of these features (see figures 3 and 4). Unlike the wind tunnel study, the flow fetch was not orthogonal to the building. Rather, the angle of approach had to be adjusted so that it would coincide with the prevailing wind flow. The millimeter wind tunnel dimensions were then rescaled to a building scale (meters). The five meteorological towers positions were placed on the north, northEast, south, and southWest sides of the building, as well as on the roof (center).

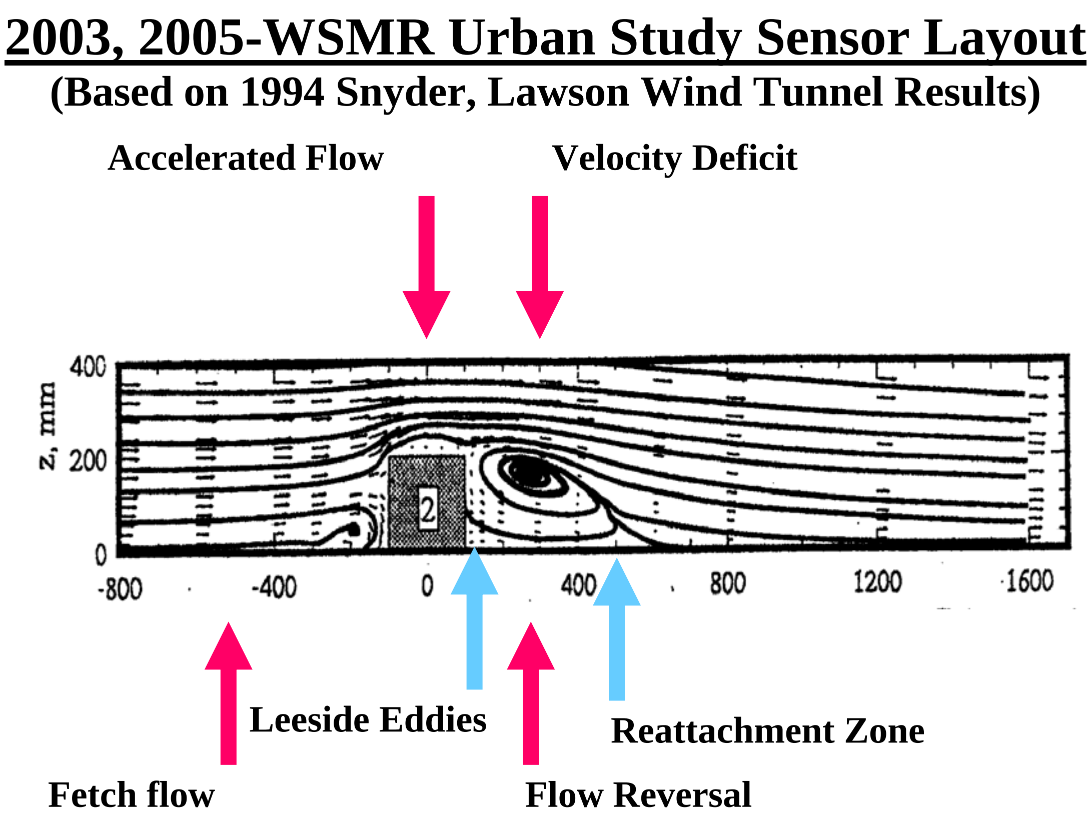

Figure 2. The *WSMR Urban Study* design was based on the 1994 Snyder/Lawson Wind Tunnel results. In 2003, the focus was to verify the fetch flow, accelerated flow, velocity deficit, and flow reversal. In 2005, the original four attributes were verified again, along with the horizontal leeside eddies and the reattachment zone.

Field Site Layout

(Not drawn to scale)

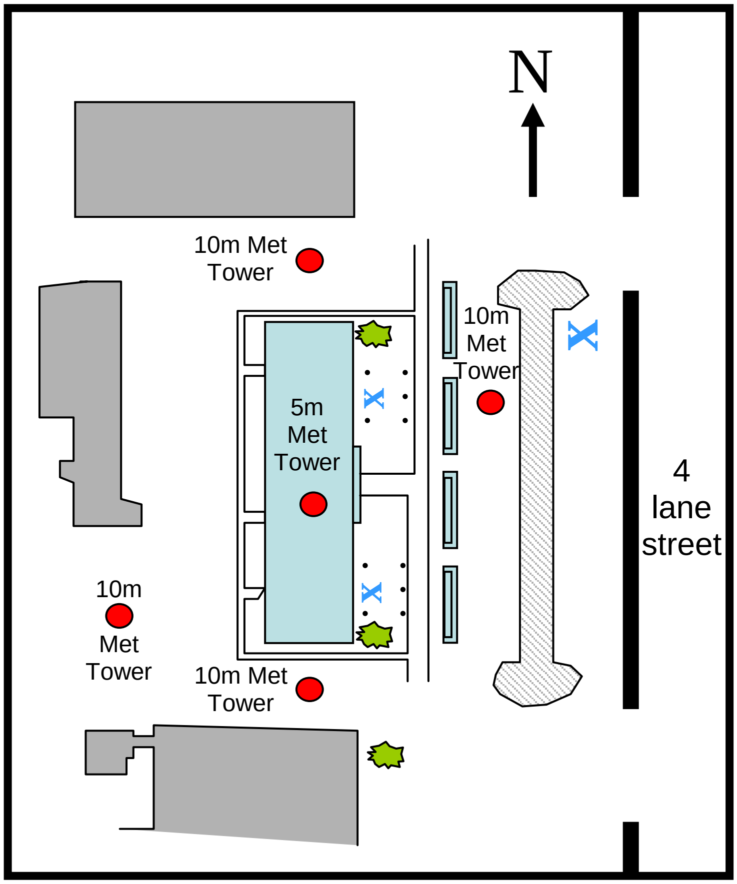

Figure 3. The *2003* and *2005 WSMR Urban Study* five tower positions (red dots) included a fetch tower southWest of the subject building, a roof tower over the building, a leeside tower in the northEast, a north side tower, and a southside tower.

NOTE: The *2005 WSMR Urban Study* 2-m tripods are noted with an X. The small dots around the X's show the configuration of the flagged fence posts (see table A-3). There is a divided parking lot to the east of the building and a four-lane street beyond the thick line. The surrounding buildings are filled in with gray. Trees are jagged green circles.

SUBJECT BUILDING and TOWERS

Figure 4. An image of the *WSMR 2003 Urban Study* subject building with the five towers surrounding and over it.

The 2003 sensor selection and placement on the tower were primarily a function of the optical turbulence study (and budget). The 10- and 2-m levels were instrumented with RM Young 05103 Wind Monitors (wind birds) on the tower's windward side (west) and a Campbell T107 and Vaisala HMP45AC Temperature/Relative Humidity sensors on the tower's leeside (east). On the south side, at 2 m AGL, a Kipp/Zonen CM3 pyranometer was placed. A Vaisala PTB101B barometer was mounted at 1.4 m AGL, in a white datalogger box. All sensors were linked by a Campbell CR23X datalogger mounted at the base of the tower. This logger was programmed to record 1-min averaged data, which was sufficient for the 2003 Study objectives. The data was acquired 24 hours a day from March 24-31, 2003. See appendix A for tables listing the specific sensors selected for the WSMR 2003 Urban Studies. Figure 5 shows the *WSMR 2003 Urban Study* configuration for the northEast tower.

WEST

EAST

Figure 5. The *WSMR 2003 Urban Study* northEast tower configuration consisted of wind monitors on the windward side of the tower. The leeside sensors included thermometers and a hygrometer. A pyranometer and pressure sensor were mounted on the south side.

3.2.2 2005 Urban Study Design

In 2005, the expanded dynamic objectives included validating the reattachment zone and the leeside building corner eddies, as well as acquiring turbulent parameters (see figure 2). The thermodynamic detailing sought yielded no additional demands on the sensor selection. Instead, a larger statistical data population for gleaning characteristic stability patterns was sought. Consequently, the five-tower layout was supplemented with three additional tripod mounted-sensors and yellow-flagged posts that mapped the projected horizontal leeside north- and southside corner eddies, as well as the leeside reattachment zone. Figure 3 shows the relative placement of these items for the *WSMR 2005 Urban Study* layout. The leeside vortices (2 m AGL) are displayed in figure 6 (northeast) and figure 7 (southeast). NOTE: The centered-sonic position (figure 7) was not as informative as the flow reversal position near the building (figure 6); therefore, the later sonic position was used for both leeside vortices during the field study execution.

VORTEX AT NORTH CORNER

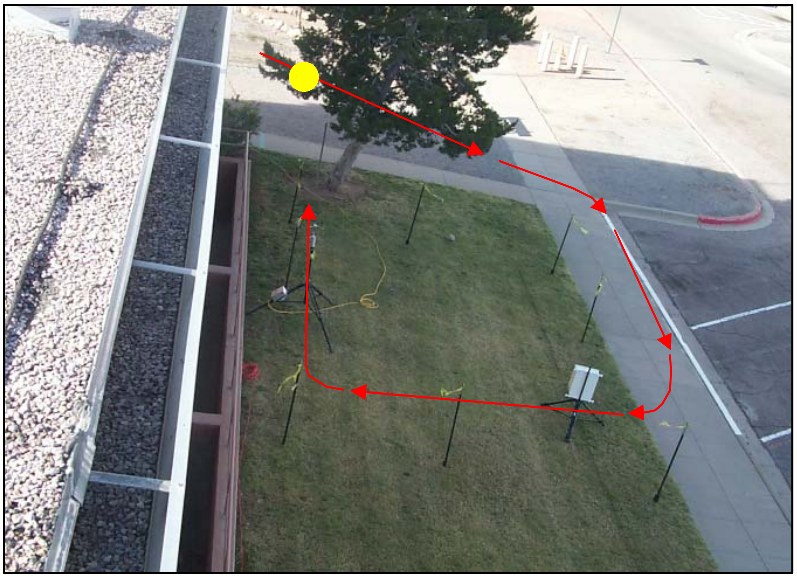

Figure 6. The northEast (leeside) corner vortex.

NOTE: The *WSMR 2005 Urban Study* horizontal corner vortices were traced with fence post flags and an ultrasonic sensor quantifying the flow reversal.

VORTEX AT SOUTH CORNER

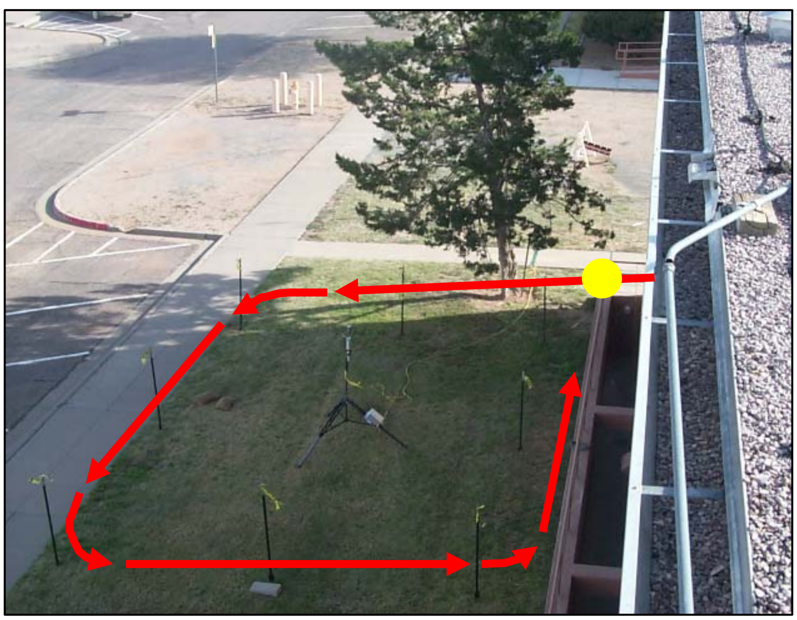

Figure 7. A *2005 Pre-Study* configuration for the southEast (leeside) horizontal corner vortex.

NOTE: This center sonic configuration was less informative than placing the sonic in the flow reversal position near the building; therefore, the reversal position was used for the actual study.

The *WSMR 2005 Urban Study* turbulence parameters required blending the 2003 mean parameter sensors with higher resolution instruments. The final sensor suite for the 2005 study included three levels (10, 5, 2.5 m AGL) of RM Young 20 Hz ultrasonics (turbulent sensors) mounted on the windward (west) side of the towers, and mean-quantity sensors attached to the leeside (east) of the tower. The leeside sensors included a Campbell T107 (10 m AGL), a RM Young Wind Monitor 05103 (5 m AGL) and a Vaisala Temperature/Relative Humidity HMP45C (2.5 m AGL). A Kipp/Zonen CM3 solar radiation sensor was placed on the unobstructed south side of the tower, and a Vaisala PTB101B pressure sensor was placed at 1.4 m in a white, data acquisition box. See appendix A for tables listing the specific sensors selected for the 2005 Urban Studies. Figure 8 shows the *WSMR 2003 Urban Study* configuration for the northEast tower.

10M

THREE LEVELS OF ULTRASONICS

5M

2.5M

TEMP, RH

WIND MONITOR

TEMP, RH PRESSURE & SOLAR RAD.

Figure 8. The *WSMR 2005 Urban Study* northEast tower configuration for the consisted of ultrasonic anemometers on the windward side of the tower. The leeside sensors included thermometers, a hygrometer and a wind monitor. A pyranometer and pressure sensor were mounted on the south side. Yellow tell-tail flags show the cavity flow.

NOTE: RH = relative humidity.

4. WSMR Urban Study Preliminary Results

A detailed account of the *WSMR 2003* and *2005 Urban Studies* results will be given in subsequent ARL publications. This report presents only the preliminary findings.

NOTE: Tower references to the east and west sides of the building are presented as "northEast" and "southWest" when their actual physical placement impacts the content of the discussion. Otherwise, a generic "East" and "West" will be used in the text.

4.1 2003 Urban Study Preliminary Results

The results from the 2003 single-day pre-study and the actual two-week-long field study can be divided into two portions: Dynamic and Thermodynamic features. Each will be addressed separately.

4.1.1 2003 Dynamic Results

The dynamic wind tunnel features flagged for validation were documented numerically, graphically and visually. Table 1 provides a representative 2003 Study data sample to be referenced in the subsequent discussion.

Table 1. Strong west wind case from *WSMR 2003 Urban Study* (Julian Date: 86.422).

Tower Height (m)	**Tower**				
	SouthWest	**Roof**	**NorthEast**	**North**	**South**
10 AGL	13.64	–	W 8.4	14.6	15.4
5 Above Roof Level	–	14.54	–	–	–
2 AGL	7.1	–	E 2.8	9.22	11.7

Numerically, the 2003 vertical wind profiles show a consistent velocity increase with height (10 m verses 2 m). Using the southWest tower data in table 1 as the reference (or Fetch Flow), a slight velocity acceleration was observed at the 5-m Roof tower. The North and South towers each report a slight velocity increase with respect to the Fetch tower at the 10- and 2-m levels. The 2-m level presents the larger velocity increase and is most likely due to the more structured channeling confines through which the air had to flow. The East tower 10-m level wind speed is slower (velocity deficit) than the 10-m Fetch tower wind speed. Yet, the wind direction remains consistent between the two towers (10 m AGL). Inspecting the East tower's 2-m level, the reduced velocity is further characterized by a reversal of flow direction. Mapping these direction changes implies the cavity flow pattern observed in the 1994 Wind Tunnel Study (Snyder and Lawson, 1994).

Examining the data graphically, figure 9 shows the 10 m (light blue) and 2 m (dark brown) wind directions. Both levels are consistent in their directions, thus confirming a good southWest location choice for the Fetch tower placement. Reviewing the coincident measurements from the East tower, there are two important patterns observed (see figure 10). First, from Julian Day

83.7 to 84, the 10-m leeside airflow continues the westerly flow of the Fetch tower and the 2-m level is from the opposite direction, thus, painting a cavity flow pattern. Later, from Julian Day 87.25 to 88.25, the less obstructed 10-m flow is from the southEast. The coincident 2-m flow has a more southerly component conforming to the east-facing wall of the building. As the more unobstructed southEastly flow hits the immovable building, the airflow is forced to realign itself along the south-north oriented building. In effect, the building is channeling the flow.

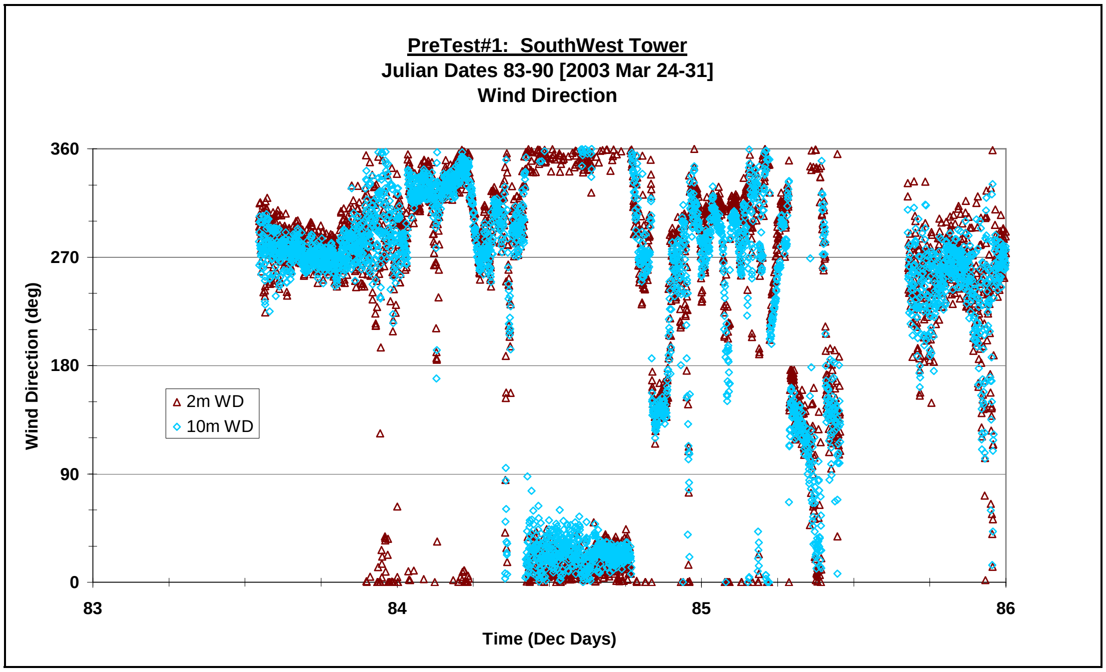

Figure 9. The *WSMR 2003 Urban Study* (*PreTest#1*) Fetch tower data for Julian Days 83-86.

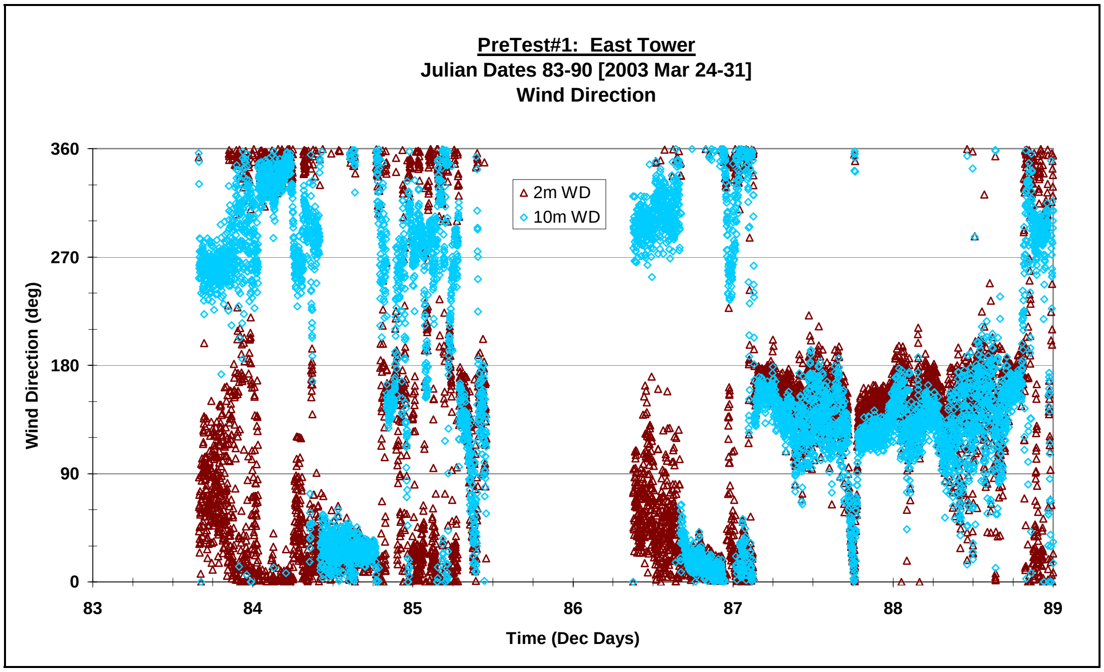

Figure 10. The *WSMR 2003 Urban Study* (*PreTest#1*) Leeside (East) tower data for Julian Days 83-86.

Finally, a pictorial display of the leeside cavity flow (northEast tower) is given in figure 11. Here, the 10-m Westerly (~270°) and the 2-m Easterly (~90°) wind flows are clearly noted in the anemometer's orientation.

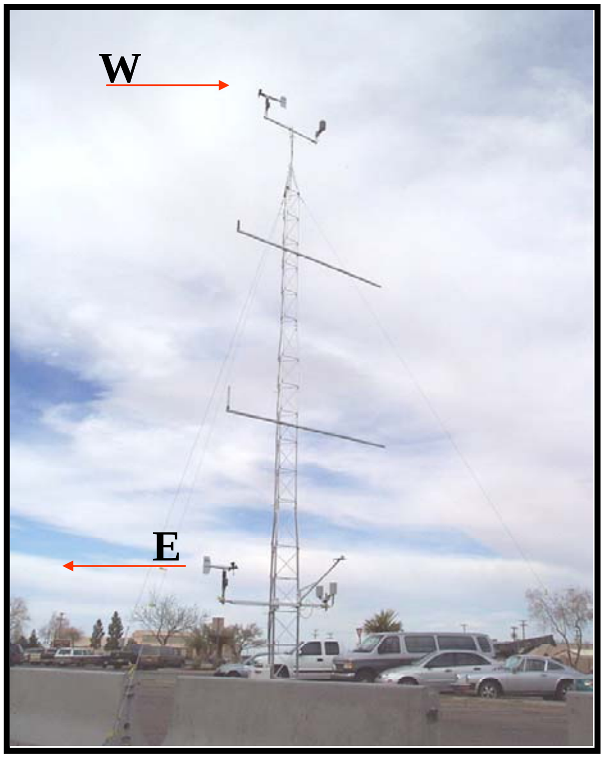

Figure 11. The northEast tower showing cavity flow by the opposing anemometer orientation.

4.1.2 2003 Thermodynamic Results

The field study's building site location was within a block of a rural southwestern U.S. desert on the south and eastern sides. To the north and west was a "small" complex of buildings comparable in size. The results of the thermodynamic parameters reflected the mix of rural and urban structures surrounding the subject building. Three thermodynamic patterns were observed:

- The rural pattern: A stable nighttime profile transitioning to an unstable daytime profile and back to a stable nighttime atmospheric structure.
- The urban pattern (small building complexes): An unstable vertical temperature profile persisting through the day and into the evening to the midnight hours.
- The urban pattern (large building complex): An unstable vertical temperature profile persisting through the day and all the nighttime hours.

The rural pattern was observed during the *WSMR 2003 Urban Study* dry run pretest and included a dramatic wind direction shift around sunrise. The small building complex-urban pattern was observed most frequently during the *WSMR 2003 Urban Study*. The large building complex pattern occurred near the close of the *WSMR 2003 Urban Study*.

4.2 2005 Urban Study Preliminary Results

The *WSMR 2005 Urban Study* preliminary results of the approximately two-week long field study can be divided into the two mission objectives: Dynamic and Thermodynamic features. Each feature is addressed separately.

4.2.1 2005 Dynamic Results

The *WSMR 2005 Urban Study* once again used the southWest tower as the windward Fetch Flow tower (a reference by which the other measurements were contrasted). The four gross flow features observed in 2003 March Urban Study were documented in the *WSMR 2005 Urban Study* two years later. These features included an accelerated flow above and along side of the building, a velocity deficit just after the building (leeside); and a flow reversal on the building leeside. In addition, the *WSMR 2005 Urban Study* results qualitatively and quantitatively located the leeside reattachment zone and detected horizontal corner vortices on the building's leeside. These findings are presented in the "Journal of Applied Meteorology" (submitted Dec. 2005).

4.2.2 2005 Thermodynamic Results

Rural or urban stability cycles were again observed in the thermodynamic data of the *WSMR 2005 Urban Study*. That is, the data reported both a nighttime stable environment transitioning to a daytime unstable environment that transitioned back to a nighttime stable environment (rural), as well as a persistent unstable condition over a 24-h period (urban). While searching for better ST characterization, the timing and duration of stable atmospheric conditions around the building were investigated. For the 2005 study, only about 6% of the 2-week long, 24 h/day data acquired reported stable conditions. When one tower reported stable conditions, all other towers reported likewise, though not necessarily at the same time. The tower recording the greatest number of minutes in stable conditions was the East tower; the least was the southWest (Fetch) tower. Second greatest number of stable condition minutes was reported by the North tower. Observing individual stable condition cases by tower, the longest duration for a single stable case was 54 min, and was reported by the East tower. When the 24-h clock was subdivided into quadrants, the time period in which stable conditions were most prevalent was from 2100 local time (LT) to 0300 LT. The second most prevalent time period was 0300–0900 LT. As expected, no stable condition was reported between
0900–1500 LT.

5. Conclusion

One building does indeed disturb the airflow and the turbulence behavior. The wind tunnel pattern generated by the single building obstruction was validated with the tower data collected in both the *WSMR 2003* and *2005 Urban Studies*. These features included a fetch flow, an accelerated flow over the roof, a velocity deficit and flow reversal (cavity flow) on the building leeside, leeside corner vortices, and a leeside reattachment zone. One of the impacts for the Soldier, regarding the validation of building corner vortices, is that their existence can lead to elevated concentrations of airborne elements on the leeside of the building. Combining these corner vortices and a leeside cavity flow could easily bring toxins released on the windward side

of a building into a centrally located front door/emergency exit. Knowledge of such flow patterns could be crucial intelligence for those strategizing safe/healthy retreats from office buildings.

One building can also create its own urban heat island. The thermodynamic patterns around the single building reported both an urban and rural cycle of stability. While these measurements do not represent a large city, patterns of a larger building complex were observed. Stable, unstable, and neutral vertical profiles were observed. The stable conditions in the *WSMR 2005 Urban Study* represented about 6% of the time sampled. The preferred time of occurrence was around midnight. The East tower reported the greatest number of minutes in a stable environment, with the North tower capturing the second largest number of stable minutes observed over the course of the field study. One of the impacts to Soldiers working in a quasi-thermally well-mixed environment would be on their ability to use thermal sighting. When rural nighttime conditions (stable/neutral) prevail, the effectiveness of thermal sighting should improve significantly. Another military application is in the area of simulation and modeling that include weather features. Most chemical-biological-nuclear simulations presume “neutral” atmospheric stability. Data from these studies indicated that all three stabilities (neutral, unstable, and to a lesser extent, stable) do occur and that their individual effects should be used as potential information for the military strategist. For Soldiers using laser technology, knowing model results from the unstable environments could have a major impact on their mission effectiveness.

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Acronyms

ARL	U.S. Army Research Laboratory
ABL	atmospheric boundary layer
AGL	above ground level
AMS	American Meteorological Society
APCA	Air Pollution Control Association
BAMS	Bulletin of the American Meteorological Society
BLM	Boundary Layer Meteorology Journal
Bubble	Basel Urban Boundary Layer Experiment
CALL	Center for Army Lessons Learned
CG	Commanding General
CISD	Computational Information Sciences Directorate
DAS	Data Acquisition System
HELSTF	High Energy Laser System Test Facility
IPR	Internal Project Review
MORSS	Military Operations Research Society Symposium
MULT	Multiplier in the sensor calibration equation.
OKC	Oklahoma City, OK
PAO	Public Affairs Office
ST	Stability Transition
VTMX	Vertical Transport and Mixing (experiment)
WSMR	White Sands Missile Range

Glossary

Campbell System	A group of meteorological sensors networked into a common Campbell data-logger box.
Sonic	RM Young Ultrasonic 81000 sensor

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Appendix A: Urban Study Sensors

The *WSMR 2003* and *2005 Urban Study* field exercises used 1-min averaged mean flow thermodynamic and dynamic measurements acquired by a Campbell CR23X micro-logger. The *WSMR 2005 Urban Study* expanded the data acquisition resources to include RM Young Ultrasonic sensors sampling at 20 Hz.

Tables A-1, A-2, and A-3 provide the details of the sensors used in each study.

Table A-1. The *WSMR 2003 Urban Study* sensor layout.

Variable	Sensor	Manufacturer	Model	Tower 2003 Sensor Height AGL (m)	Side of Tower Sensor Mounted
Pressure	Barometer	Vaisala	PTB-101B	1.4	center
Temperature	Thermometer	Campbell	T107	10	east
Temperature/ Relative Humidity	Thermometer/ Hygrometer	Vaisala	HMP45AC	2	east
Wind Speed/Wind Direction	Wind Monitor	RM Young	05103	10, 2 5 (Roof)	west west (Roof)
Solar Radiation	Pyranometer	Kipp/Zonen	CM3	2	south

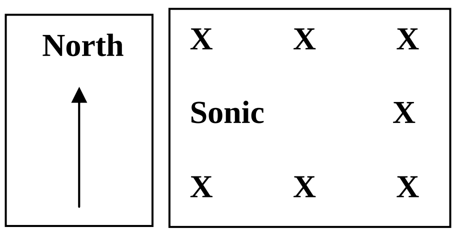
Table A-2. The *WSMR 2005 Urban Study* sensor layout.

Variable	Sensor	Manufacturer	Model	Tower 2005 Sensor Height AGL (m)	Side of Tower Sensor Mounted
Pressure	Barometer	Vaisala	PTB-101B	1.4	center
Temperature	Thermometer	Campbell	T107	10	east
Temperature/ Relative Humidity	Thermometer/ Hygrometer	Vaisala	HMP45AC	2	east
Wind Speed/ Wind Direction	Wind Monitor	RM Young	05103	5 5 (Roof)	east west (Roof)
Solar Radiation	Pyranometer	Kipp/Zonen	CM3	2	South

Table A-3. The *WSMR 2005 Urban Study* utilized sensors to map turbulent measurements.

Variable	Sensor (Sample Rate)	Manufacturer	Model	Tower Sensor Height AGL (m)	Side of Tower Sensor Mounted	Tripod Sensor Height AGL (m)
Wind speed/direction, temperature, speed of sound	Ultrasonic Anemometer (20 Hz)	RM Young	Sonic 81000	2.5, 5, 10 5 (Roof)	west	2[a]
Wind direction[b]	Fence post with yellow flag on top				n/a	~2[c]

[a]center
[b]located in the northeast and southeast corners of building
[c]Fence post pattern with 2-m-Sonic on West-center side of the design; fence post positions are indicated by the "X". Flags were tied at about 2 m AGL. The subject building east wall runs north-south along the left side of this pattern.



NOTE: See figure 3 for tower and tripod locations.

Appendix B: A Field Study Timeline Template (*WSMR 2005 Urban Study* Milestones)

There are many details that go into a quality field study. The following chronological outline highlights some these *WSMR 2005 Urban Study* details and is offered as a template for future field studies.

Summary of Details

B-1.	2004 Aug.-2005 Mar.:	Urban Study Preparations
B-2.	2005 Feb./Mar.:	Pre-Study Sensor and Systems Calibrations
B-3.	2005 Mar./Apr.:	Urban Study-Field Portion (March 21 to April 1, 2005)
B-4.	2005 Apr./May:	Post-Study Calibration/Preliminary Urban Study Data Analysis
B-5.	2005 May 4:	Initial Urban Study Summary submitted to Supervisor

B-1. 2004 Aug.-2005 Mar.: Urban Study Preparations

1. 2004 August/September (Administrative (admin) Tasks)
    a. Selected the Urban Study participants.
    b. Drafted the Urban Study-Test Plan/Test Method.
2. 2004 October/November (Admin/Hardware)
    a. The Urban Study was cancelled then reinstated, due to unsolicited interest expressed by national (Pacific Northwest National Laboratories) and international (Dr. Oke, Canada) researchers.
    b. Selected new participants, since the original participants were already assigned to other projects.
    c. Updated the Urban Study Test Plan/Test Method.
    d. Investigated several Sonic Data Acquisition Systems (DAS), such as those developed by Vidal, Tofsted, Noble, and described in vendor manuals.
    e. Researched various Sonic software options.
3. 2004 November (Admin/Hardware)
    a. Detailed the Urban Study Test Plan/Test Method to include the equipment layout.
    b. Initiated an ARL-WSMR sensor inventory.
    c. Calculated supply needs for the massive amount of data output anticipated.
    d. Investigated Campbell and Sonic hardware workspaces available within U.S. Army Research Laboratory (ARL)-White Sands Missile Range (WSMR) buildings.

e. Drafted a Sonic system design. Discovered a Sonic purchase order; monitored status through the COR.

f. Software: Converted most of donated Sonic data processing programs from MATLAB 13 to MATLAB 5.3 programs. (The only MATLAB version available to this research project was MATLAB 5.3.)

4. 2004 December (Admin/Hardware)
   a. Final Urban Study Test Plan signed by all participants and supervisor.
   b. Attempted to bring in additional meteorological technician assistance; the budget decision-maker rejected proposed assistance.
   c. Campbells: Initiated Campbell sensor design and software programming training.
   d. Sonics: Seasoned expert reviewed Sonic DAS design. Twenty new RM Young Ultrasonics arrived.
   e. Software: Selected Excel for data plotting routines. Ran sample data. Validated the timestamp.
   f. DAS logistics: Designed filenames for greater efficiency and understanding.
   g. Publication: Submitted an Urban Study Military Operations Research Society Symposium (MORSS) abstract to ARL for approval.
5. 2005 January
   a. Admin
      i. Received all required permissions for Urban Study execution.
      ii. Initiated weekly (versus bi-monthly) progress report/coordination meetings.
      iii. Created an Urban Study Open House agenda. Invited ARL and non-ARL guests to attend.
      iv. Initiated peer reviewed dry run briefings by Urban Study Open House participants.
   b. Campbells:
      i. Completed the Campbell tower design.
      ii. Learned and validated Campbell wiring for all 20 sensors.
      iii. Wrote and tested a Campbell micro-logger program for all towers.
      iv. Validated all Campbell programs with Campbell Scientific and High Energy Laser System Test Facility (HELSTF) resources.
      v. Developed an Excel template for displaying all Campbell data within an hour of acquisition.
      vi. Conducted trial calibration tests on dynamic Campbell sensors and reviewed the results.
      vii. Initiated an endurance (duration) test for Campbell Systems.

viii. Initiated a timestamp test for Campbell Systems.

c. Sonics

i. Placed orders for Sonic DAS parts; salvaged parts from available internal resources.

d. Software

i. Returned to MATLAB 5.3 for Sonic 20-Hz data plots, since Excel could only plot 15 min of data

ii. Created Sonic plotting software based on sample data set.

iii. Publication: The ARL-approved Urban Study abstract was submitted to "invitation only" MORSS.

B-2. 2005 Feb./Mar.: Pre-Study Sensor and Systems Calibrations

1. 2005 February

a. Admin

i. Continued peer reviewed dry run briefings by Urban Study Open House participants.

ii. Designed and located supplies for multiple archives and data plots.

b. Towers

i. Conducted a 3-day end-to-end, Pre-Study tower check – all tower/booms/ tripods were checked for parts and all parts measured/drilled for proper placement.

ii. Located all outdoor extension cords.

c. Lab/Calibration Test

i. Conducted pre-study lab/calibration test for Campbell and Sonic systems.

ii. Completed DAS time checks on Campbell and Sonic systems.

iii. Concluded a Campbell duration test (33 days of data).

iv. Plotted all Campbell and Sonic data acquired.

v. Reviewed and discussed results.

d. Campbell

i. Validated the multiplier in the sensor calibration equation (MULT) and the Offset values for all Campbell system sensors.

e. Sonic

i. Constructed (literally) a Sonic hardware design. Processed the needed purchase requests.

B-3. 2005 Mar./Apr.: Urban Study-Field Portion

1. 2005 March
   a. Admin
      i. WSMR Commanding General (CG) briefing: Drafted an Urban Study summary for the WSMR CG briefing (Mr. Reed Elliott presented briefing).
      ii. Griffin Summary: Drafted a summary of Urban Study Open House for General Griffin.
      iii. News Media: Was contacted by the "WSMR Missile Ranger." The ARL-Public Affairs Office (PAO) did follow up.
      iv. Generated an Urban Study Internal Project Review (IPR) questionnaire for Post-Study "lessons learned" discussions.
   b. Calibration Test
      i. Completed a Pre-Study Sonic Side-by-Side Calibration Test for all 22 Sonics.
      ii. Plotted and reviewed all Sonic data. Identified suspect Sonic sensors.
      iii. Attempted to incorporate a Licor System from another project into this field study, as per request.
   c. Sonic
      i. See Calibration Test (item b).
      ii. Fine-tuned Sonic software programs for 1-min average and 20-Hz data displays.
      iii. Displayed and reviewed calibration results within 24-h of acquisition.
   d. Software
      i. Refined the Excel and MATLAB 5.3 plotting programs based on Calibration Test data.
      ii. Improved the archive design based on the Calibration Test results.
   e. Urban Study Execution
      i. Assembled towers/tripods/posts with help from military personnel.
      ii. A trained technician inspected all the equipment.
      iii. Switched out two Sonics due to malfunctioning in the new sensor probes. (Daily data checks flagged this glitch.)
      iv. Fine-tuned the vertical alignment of Sonics using a Cherry Picker truck.
      v. Documented milestones.
      vi. Acquired data from 36 sensors for ~16 days in March (4 in April).
      vii. Downloaded, archived, processed, and reviewed all data daily.

viii. Independently acquired synoptic and mesoscale meteorological data daily during Urban Study execution.

ix. Conducted a daily status check of all systems and study objectives.

f. Open House

i. Completed the ARL Form 1 for the Urban Study Open House briefing slides.

ii. Conducted the Urban Study Open House dry run. (ALL Study participants gave briefings.)

iii. Successfully completed the Urban Study Open House, which included a number of inside briefings and an outside tour of the towers/tripods and sensors during an ideal windy New Mexico March day. (Open House attended by multiple organizations and ARL-BE Division Chief.)

B-4. 2005 Apr./May: Post-Study Calibration and Preliminary Urban Study Data Analysis

1. 2005 April

a. Completed the field study portion of the Urban Study.

b. Plotted and archived all field study data.

c. Disassembled and stowed towers/tripods/posts with help from military personnel.

d. Initiated preliminary Urban Study analysis and summary.

e. The Daily Coordination Meetings were rescheduled to weekly occurrences.

f. Post-Study Sonic Calibration

i. Assembled Side-by-Side Sonic Calibration setup.

ii. Ran three consecutive sets of Side-by-Side Sonic Calibration Tests (which included all Sonic sensors utilized in this Study).

iii. Downloaded, archived, processed, and reviewed all Sonic data each workday.

iv. Acquired synoptic and mesoscale meteorological data daily during Calibration Test.

v. Conducted a status check of Sonic systems each workday.

vi. Dissembled the Side-by-Side Sonic Calibration equipment.

g. Campbell Systems

i. Assembled the Side-by-Side Thermodynamic Campbell System Calibration setup.

ii. Downloaded, archived, processed, and reviewed all Campbell data each workday.

iii. Acquired synoptic and mesoscale meteorological data daily during Calibration Test.

iv. Conducted a status check of systems each workday.

2. 2005 May

   a. Campbell Systems (continued)

      i. Ran an 1800 RPM test of the Wind Monitors.

      ii. Disassembled and stowed all calibration equipment.

      iii. Downloaded, archived, processed, and reviewed all Campbell data.

      iv. Acquired synoptic and mesoscale meteorological data daily during Calibration testing.

   b. The weekly Coordination Meetings were rescheduled to monthly or bi-weekly occurrences (as per the Urban Study data analysis effort requirements).

   c. Preliminary data analysis was conducted.

   d. Post-Study publication titles and outlines were drafted.

   e. Detailed Post-Study data analysis was initiated.

   f. The Preliminary Urban Study Summary was submitted to supervisor.

B-5. 2005 May 4: Initial Urban Study Summary Submitted to Supervisor

The following text is from the Initial Urban Study Summary submitted to the Supervisor. The Summary consists of the following sections:

1. General Information.
2. Project Milestones. (See appendix B.)
3. IPR Results. (See appendix C.)
4. Preliminary Scientific Results.
5. References. (See references section.)
6. Administrative Summary (separate document, available upon request).

Items 2, 3, and 5 are not included here since they have already been presented in appendices B, C, and the Reference sections, respectively.

1. General Information

Title: White Sands Missile Range 2005 Urban Study: Flow and Stability Around A Single Building.

Customer: The U.S. Army Soldier is our customer.

NOTE: This project is step 2 in a 5-step cycle aimed at improving the Soldiers' ability to get their job done more efficiently and effectively in an urban environment.

Given: The Soldier has urban warfare tools and tasks. The steps needed are as follows:

1. Identify shortfalls of these tools and tasks in the urban environment.
2. Identify atmospheric patterns relevant to rectifying the shortfalls.

3. Quantify these atmospheric patterns in algorithms that evolve into models.
4. Validate models/atmospheric patterns.
5. Correlate models with Army tools/tasks and design/develop decision aids.

6/1 Re-evaluate Soldier tools and tasks used in urban warfare.

1. Atmospheric impacts causing urban military tools and tasks shortfalls can be grouped into two categories: Dynamic (wind) and Thermodynamic (temperature/solar radiation) atmospheric impacts.

   1.1 Dynamic: The Center for Army Lessons Learned (CALL) (1999) documented that urban area flight operations (including aircraft performance and weapon delivery) were adversely impacted by broken up and street/alley funneling winds, as well as canyon turbulence. The "Aviation Urban Operations" manual (2001) associated wind patterns with the degradation of night vision systems, communications, visibility, and toxic fumes. The behavior of smoke and chemical/biological materials is also of major important operations within an urbanized area/MOUT site.

   1.2 Thermodynamic: CALL (1999) reported adverse affects on military aircraft thermal sights in the urban environment, citing the thermal heating by buildings as a potential explanation for these effects. Also reported was reduced visibility due to urban smog, which caused increased target acquisition threat exposure time. Weapon sensors in the urban environment were labeled as degraded, and laser guided weapons were specifically flagged as being severely affected.

2. To identify atmospheric patterns relevant to rectifying shortfalls, the *WSMR 2003 March Urban Stud*y and *WSMR 2005 Urban Study* were designed.
3. Quantifying the atmospheric impacts generated two Scientific Objectives:
   - To characterize behavior of turbulent flow around and above a single building.
   - To characterize surface layer stability patterns in an urban environment.

   The Project Plan/Method includes the following:

   - *Objective 1 (Dynamics)*: To optimize field study conditions pertinent to the wind behavior, the New Mexico windy season (March/April) was selected.
   - *Objective 2 (Thermodynamics)*: To minimize systematic seasonal effects on the daily heating/cooling cycles, the equinox time period (March) was selected.
   - *Test Site Location and Equipment*: Test site location and equipment choices were defined primarily by budgetary constraints. The test site was at WSMR and centered around the ARL two-story office building. The equipment selections are explained in the next sections (sensor selection and sensor location).
   - *Sensor selection*: Details of the Campbell CR23X micro-logger and the R.M. Young ultrasonic are given in tables B-1 and B2, respectively.

Table B-1. Mean flow measurements acquired by a Campbell CR23X micro-logger.

Variable	Sensor	Manufacturer	Model	Tower Sensor Height AGL (m)
Pressure	Barometer	Vaisala	PTB-101B	1.4
Temperature	Thermometer	Campbell	T107	10
Temperature/ Relative Humidity	Thermometer/ Hygrometer	Vaisala	HMP45AC	2
Wind Speed/ Wind Direction	Wind Monitor	RM Young	05103	5
Solar Radiation	Pyranometer	Kipp/Zonen	CM3	2

Table B-2. Turbulent measurements employed the 20-Hz sampling rate of the R.M. Young ultrasonic.

Variable	Sensor	Manufacturer	Model	TowerSensor Height AGL (m)	Tripod Sensor Height AGL (m)
Wind Speed/Dir, Temperature, Speed of Sound	Ultrasonic Anemometer	RM Young	Sonic 81000	2.5, 5, 10	2
Wind Direction-Located NE & SE corners of building	Fence post with flag on top				~2

- *Sensor Layout*: The layout was defined by identifying the four gross features described by a Snyder and Lawson wind tunnel study (1994) and optimizing the quantitative opportunities for capturing these features. Adjusting for scale and prevailing wind flow angles, five towers and three tripods were strategically placed around a single building. Turbulent sensors were mounted on the windward (west) side of the towers. Mean flow sensors were attached to the leeward (east) tower side. The solar radiation sensor was placed on the unobstructed south side of the tower.

2. Project Milestones

See appendix B.

3. IPR Results

See appendix C.

4. Preliminary Scientific Results (Phase I/II)

Dynamic Features: One building does disturb the airflow. Using the windward tower as the standard by which the other measurements are contrasted, the four gross features observed in March 2003 field study were documented in the *WSMR 2005 Urban Study* conducted in March 2005. These features included an accelerated flow above and along side of the building; a velocity deficit just after the building (leeside); and a flow reversal on the building leeside. The

WSMR 2005 Urban Study expanded the building flow features by qualitatively and quantitatively detecting corner vortices. The criteria for vortex generation and degeneration appeared to be based upon wind direction, wind speed range, and stability. One of the impacts for the Soldier is a validation that the corner vortices lead to elevated concentrations of airborne elements on the leeside of the building (Cermak et al., 1974).

Thermodynamic Features: One building can create its own urban heat island. The thermodynamic patterns around the single building studied reported both a rural or urban cycle of stability. That is, the data reported both a nighttime stable environment transitioning to daytime unstable environment and back to nighttime stable environment (rural), as well as, a persistent all-unstable condition over a 24-h period (urban). While these measurements do not represent a large city, one of the impacts to the Soldiers would be their the ability to use thermal sighting. When rural conditions prevail, the effectiveness of thermal sighting should improve significantly. Another Soldier application is in the area of simulation modeling with weather features as part of the input. Most chemical-biological-nuclear simulations will presume "neutral" atmospheric stability. Data from these studies indicated that all three stabilities (neutral, unstable, and to a lesser extent, stable) do occur and should be used as potential information for the military strategist.

5. References

See references section.

6. Administrative Summary

Separate document, available upon request.

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Appendix C: *WSMR 2005 Urban Study* Internal Project Review (IPR) Results

The *WSMR 2005 Urban Study* IPR questionnaire addressed four issues:

C-1 Major Milestones

C-2 Lessons Learned

C-3 Post-Study Action Items (and Point of Contact)

C-4 Comments/Suggestions

The four sections that follow list statements submitted and discussed by the participants at the *WSMR 2005 Post-Urban Study* IPR.

C-1 Major Milestones

C.1.1 Overall Study

The following tasks were completed successfully:

- Designed and executed the WSMR 2005 Urban Field Study Plan/Method.
- Overcame field study hurdles including locating equipment, workspace, personnel, permissions, etc.
- Completed the Urban Study Open House.
- Acquired, archived, plotted, and ran a preliminary data analysis within 24 h of acquisition!

C-1.2 Scientific Objectives

The following tasks were completed successfully:

- Collected several days of optimum vertical and horizontal eddies data.
- Conducted Pre-/Post-Study Side-by-Side Calibration Tests of all sensors.
- Visualized and measured corner eddy structures using stakes with flags and sonics.

C-1.3 Campbell Systems

The following tasks were completed successfully:

- Documented the micro-logger software programming.
- Located all relevant system components in one area (verses the original five areas).
- Defined the lab area for hardware setup and testing.
- Defined a good pretest method that can be used for future urban studies.

C-1.4 Sonic Systems

The following tasks were completed successfully:

- Developed software for recording Sonic serial data flow.
- Developed a system for consistent time-stamping of data.
- Developed a wireless communication system with automated data transfer.
- Configured a complete system from collection of subsystems.

C-1.5 Software

The following tasks were completed successfully:

- Developed data presentation software for Campbell System in Excel.
- Developed data presentation software for RM Young Sonic System in MATLAB 5.3 language (with backup in Excel).

C-1.6 Mesoscale/Synoptic Weather

The following tasks were completed successfully:

- Collected and archived freely available mesoscale and synoptic data from Web.
- Used data to verify larger scale weather regime on urban test days.
- Saved data as .png, .fig, and .txt files.
- Provided weather forecasts, briefings and updates to Urban Study team members.

C-2 Lessons Learned

C-2.1 Overall Study

- Field studies might be easier with non-mission budget support (during lean years).
- Need to attach specific model applications (verses just a wind tunnel validation) to field studies before Study execution.
- Need to improve Study public relations advertisements.
- Using the Cherry Picker truck to fine-tune alignments after all the towers were in place was a great idea.
- The Urban Study Open House allowed participants to answer inquiries of other organizations/projects.
- Weekend monitoring of sensors would help minimize data loss, but would require additional comp time.

C-2.2 Scientific Objectives

- A qualitative review of side-by-side Sonic comparisons to identified problem sensors was a good idea.

- The Environmental Protection Agency wind tunnel study and additional analysis allowed the towers to be located correctly the first time.
- More flex time should be built in to allow for unavoidable downtime (admin, weather, etc).
- Don't borrow equipment, if at all possible.
- Daily data downloading, systems checks, and data plotting optimized operational and scientific confidence.
- Eddy structure is transitory until strong synoptic-driven conditions prevail.

C-2.3 Campbell Systems (20 sensors)

- Documentation is critical for the success of the data acquisition.
- Pre-calibration and independent program validation helped to build data confidence.

C-2.4 Sonic Systems (16 sensors)

- Wireless networking is very sensitive to variable conditions.
- Preparation for rapid replacement of critical components is essential.
- Documentation is invaluable for post-study analysis.
- Keeping sensors in numerical serial number order assisted in tracking Sonic performance – before, during, and after the field *Study*.

C-2.5 Software

- Excel worked well with the multi-sensor Campbell data.
- MATLAB 5.3 worked well with the 20-Hz RM Young (Sonic) data.
- MATLAB 13 programs are not easily reverse-compatible with the older MATLAB 5.3 software.

C-2.6 Mesoscale/Synoptic Weather

- Standardizing the larger scale weather resources database before the study begins would be useful.
- Automating archival would be useful (the manual approach took much time).

C-3 Post-Study Action Items

NOTE: Those items already completed as of this report are marked "– done".

C-3.1 Overall Study

- Post-Study Calibration of all 36 sensors needs to be completed – done.
- Urban Study Preliminary Summary needs to be written – done.
- The Military Operations Research Society Symposium (MORSS) presentation needs to be assembled – done.
- ARL technical reports need to be identified – done.

- Open literature papers ("Bulletin of the American Meteorological Society," "Boundary Layer Meteorology Journal") need to be drafted – done.
- Recognition awards and thank you notes need to be written and sent – done.

C.3.2 Scientific Objectives

- Quantitative review of side-by-side Sonic comparisons and documented results.
- Quantitative review of side-by-side Campbell comparisons and documented results.

C-3.3 Campbell Systems (20 sensors)

- Generate a wireless version of this Campbell systems setup.
- A CD of the Campbell archive needs to be generated – done.

C-3.4 Sonic Systems (16 sensors, with 6 alternate sensors)

- Obtain new components to design, assemble, and test a more robust DAS.
- End of study timestamp check needs to be documented – done.

C-3.5 Software

- Build programs for Post-Study data analysis.

C-3.6 Meso/Synoptic Weather

- Provide cleaned up dataset to Test Director with a README file.

C-4 Comments/Suggestions

"Great teamwork!"

"Need to do a similar study at High Energy Laser System Test Facility (HELSTF) and at WSMR headquarters."

"This Study is good preparation for a Study at the Homeland Security Site of Playas, NM."

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